Fermi National Accelerator Laboratory

FERMILAB-Conf-94/343-E

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September 1994

Presented at the *8th International Symposium on Very High Energy Cosmic-Ray Interactions,* Tokyo, Japan, July, 24-30, 1994

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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Abstract

We report preliminary results of a Monte Carlo study to search for Centauro events in the DØ Detector at Fermilab. Montecarlo simulation of minimum bias events are being carried out using the ISAJET and DØGEANT packages to study the detector response for low energy particles and to understand the background. Preliminary indications are that the detector is capable of resolving individual particles. Further work on developing reconstruction algorithms for individual particles is in progress.

1 Introduction.

The Brasil-Japan (B-J) collaboration group found in their emulsion chamber exposed to cosmic rays at Mt. Chacaltaya (atmospheric depth 530 g/cm^2) a strange event which they named as Centauro-I[1]. It is the first example of an extremely rich hadron family, which is interpreted as due to a new type of nuclear interaction with production of about 100 hadrons without emission of gamma-rays (neutral pions). Further searches from B-J group has revealed four more events of Centauro type[2] and one from Pamir experiment[3] but none from Mt. Fuji[4] and Mt. Kanbala[5] experiments. However the Centauro-I event stands out completely from the sample as it is the only event with extremely small gamma-ray (the term gamma-rays will hereafter be used to denote electrons and gamma-rays) content but rich in hadron content and hence attracted a great deal of attention. All other events have gamma-ray content comparable to that of hadrons. The energy of the Centauro event is estimated to be 1500 TeV in the lab system. Accelerator searches for Centauro type of interactions ended in null results so far[6–8].

*Paper presented at the 8^{th} International Symposium on Very High Energy Cosmic-Ray Interactions, 24-30 July, 1994, Tokyo, Japan.

Besides the B-J group, efforts were made by many others to understand the Centauro-I event[9–26]. Bjorken and McLerran[10] postulated the existence of a new component, a dense primordial glob of nuclear matter or quark matter, in the primary cosmic radiation, which penetrates deep in the atmosphere and gives rise to Centauro-I type of event. Kinnunen and Rubbia[15] consider the possibility of production of Centauro events due to hard collisions between hadronic constituents and rule out the same based upon flux considerations.

The possibility that the fluctuated air shower cores mimic Centauro type of events has been studied in great detail[20–26]. No one has succeeded in reproducing the Centauro-I event though other events of Centauro type were reproduced. Acharya *et al*[24] have shown through Monte Carlo simulations that those Centauro events in which gamma-ray content is comparable to that of hadrons, could be understood as extreme fluctuations in air shower cores using conventional physics and concluded that these events do not belong to the same class of events as Centauro-I. The possibility that a heavy nucleus interacting rather low in the atmosphere and give rise to Centauro-I type of event was considered by Acharya and Rao[27]. They have shown that it is possible to reproduce the event, though the total number of such events expected in the global data is 2×10^{-5} as against one observed event.

Earlier searches at accelerators were carried at the CERN SPS collider at center of mass energies of 540 and 900 GeV, corresponding to laboratory energies of 146 and 400 TeV respectively. The negative results from these searches is perhaps because the energies are below the threshold for production of Centauro events. The center of mass energy at the Fermilab collider is 1.8 TeV, corresponding to 1,600 TeV in the laboratory frame. Therefore, if Centauro events are produced in high energy collisions, they should be seen at the Fermilab collider.

The DØ detector, operating at the Fermilab collider, has charged particle tracking capability up to 3.2 units of pseudorapidity, a nearly hermetic liquid argon calorimeter covering a range of approximately 4 units of pseudorapidity and capable of separately measuring electrons and hadrons, and a muon spectrometer. Thus, it is well suited to search for Centauro type of events. In the following sections, we shall briefly describe the DØdetector and present some preliminary results of Montecarlo studies.

2 The DØ Detector

The DØ Detector is primarily designed to study high mass states and large p_T phenomena. It basically consists of three elements : the Central Detector, the liquid Argon-Uranium calorimeter and the outer muon detector. A schematic of the detector is shown in Fig. 1. Details of the detector can be found elsewhere[28].

2.1 The Central detector

The central detector consists of the Vertex Drift Camber (VTX), the Transition Radiation Detector (TRD), the Central Drift Chamber (CDC), and two Forward Drift Chambers (FDC).

The VTX chamber is the innermost tracking detector and provides a track resolution of 60 μm. The efficiency of separating a pair of tracks by at least 0.63 mm is 90%.

The TRD detector occupies the annulus between the VTX and the CDC and serves to give added, independent electron identification to that afforded by the calorimeters in the region $|\eta| < 1.6$. It responds to particles with Lorentz factor $> 10^3$. It provides a rejection factor of approximately 50 for pions while retaining an efficiency of 90% for electrons.

The CDC provides coverage for tracks at large angles, after the TRD and just prior to their entrance into the Central Calorimeter. The FDC's extend the coverage down to 5°degrees with respect to both emerging beams. Spatial resolutions in the CDC and FDC vary between 150-200 μm.

2.2 The Calorimeters

The DO Calorimeter is a Uranium - liquid Argon sampling calorimeter with a semi-projective geometry. A schematic of the Calorimeter is shown in Fig. 2. It has a nearly 4π solid angle coverage. The Calorimeter is divided into three separate sections: one Central Calorimeter (CC) and two End Calorimeters (EC). Together they cover the whole region of $\eta - \phi$ space, except for a small region around $\eta = 1.35$, where there is no coverage for electrons. In the region $0.8 < |\eta| < 1.4$, an array of scintillators, called the Inter Cryostat Detector (ICD), and additional sampling detectors called Massless Gaps (MG) are installed to improve the performance.

The CC is of modular construction. It consists of three concentric cylinders of modules of about nine feet in length. The first ring of 32 modules is the Electromagnetic (EM) section for the energy measurement of electrons and photons. Each EM module is subdivided into four readout layers. The next ring of sixteen modules is the Fine Hadronic (FH) section. These modules are divided in radial depth into three readout layers. The last ring of sixteen modules is the Course Hadronic (CH) section; each module has only one readout layer. The EM section has a total depth of 20.5 radiation lengths, and the EM, FH and CH sections together present a total of 7.16 nuclear interaction lengths to hadronic showers. The EM and FH modules use uranium as absorber material , while the CH uses copper. The CC has a segmentation in η and ϕ of $\delta\eta = \delta\phi = 0.1$ in most of the readout layers of the calorimeter. The exception is the third layer of the EM modules where the shower maximum for electromagnetic showers is expected. It has transverse segmentation $\delta\eta = \delta\phi = 0.05$. This allows for better position resolution.

The EC is also modular in construction. The EC EM module faces towards the center of the detector. Behind the EC EM and centered is the Inner Hadronic (IH) module. In a concentric ring around the IH module are the sixteen Middle Hadronic (MH) modules. And in a concentric ring around the MH modules are the sixteen Outer Hadronic (OH) modules. The EC EM has a total of 23.3 radiation lengths divided into four readout layers. The IH and EM combine to give 8.2 nuclear interaction lengths. The MH and OH rings, together with the IH and EC EM, give the same number of interaction lengths over the full containment range of the EC. The segmentation in η and ϕ is the same as in the CC except at the higher values of η, $|\eta| > 3.2$ ($|\eta| > 2.6$ for third EM layer).

The ICD consists of two rows of boxes, containing scintillating tiles, mounted on the EC wall. The size of the tiles is such that they conform to the transverse segmentation of the calorimeter.

The Calorimeter was calibrated using test beams of electrons and pions in the energy range 2-150 GeV in fixed target runs. From this data, the linearity of the Calorimeter response with energy, energy and position resolution, the ratio of the Calorimeter response for electrons and pions (e/π ratio), uniformity and shower shape were determined. The response of the Calorimeter is linear above 10 GeV and the deviation from linearity below 10 GeV is no more than 5%[29]. The energy resolution is approximately $15\%/\sqrt{E}$ for electron and approximately $50\%/\sqrt{E}$ for hadrons. The position resolution is $\sim$ 1 mm for electrons and 10 mm for pions.

2.3 Muon Detector

The muon detector consists of two subsystems; the Wide Angle Muon Spectrometer (WAMUS) for the central region and the Small Angle Muon Spectrometer (SAMUS) for the end regions. They are located beyond the Calorimeter region and consist of three layers of proportional drift tubes (PDT) and magnetized iron between the innermost two layers. The magnetic field is 2 tesla. The system covers the region $|\eta| < 3.3$.

2.4 Level 0 Hodoscopes

The information on whether $\overline{p}p$ collisions occurred during a beam crossing is supplied by two sets of scintillator hodoscopes. This information consists of a comparison between the time of arrival of particles in the forward and backward directions as they interact with the hodoscopes. The hodoscopes are located in space between each of the two EC's and FDC's. Each consists of two planes. They give a nearly complete coverage over $2.2 < |\eta| < 3.9$ and at least partially over $1.9 < |\eta| < 4.3$.

2.5 Trigger

The DØ trigger scheme is divided into three levels and one sublevel. The Level_0 trigger comes from the Level 0 hodoscopes and indicates the occurrence of an inelastic interaction. It discriminates against the beam-gas interactions and also supplies the next level of trigger, Level_1, with coarse vertex information and information on multiple interactions. Level_1 is a hardware trigger and is divided into 31 sets of programmable trigger conditions, which are thresholds on various detector variables. It reduces the trigger rate from basically the crossing rate of about 300 kHz, corresponding to a luminosity of about $5 \times 10^{30} cm^2 s^{-1}$, to about 200 Hz. Level_1.5 is basically a trigger on muon momentum and it reduces the rate to no more than 100 Hz. The Level_2 trigger is a software filter and is the most complicated. It reduces the trigger rate to no more than 2 Hz, which is DØ's maximum on-line data handling rate for writing data to tape. For each of the 31 Level_1 triggers that are satisfied, a set of Level_2 filters are called which are particle specific algorithms with various thresholds. Details of the triggering system can be found elsewhere[30–33].

The events that will be used to search for Centauro events are collected using the MIN_BIAS trigger. This trigger requires a good Level_0 trigger and no other filter.

3 Method of Analysis

The strategy of the search for Centauro events in the DØ Detector depends on the interpretation of the event. The Brasil-Japan group's interpretation is that a fireball of mass $\sim 230 GeV/c^2$ is produced, which decays into $\sim$ 100 baryons and antibaryons. In this case, the decay particles are distributed isotropically in the center of mass system with a mean p_T of $\sim$ 2.3 GeV/c. No π^0 s are produced.

In this case, we expect a large energy deposit in the hadron calorimeter with no energy in the EM calorimeter due to π^0 s. As the particles involved are of low energy, with an average energy of a few GeV, the low energy response of the calorimeter has to be carefully studied. While the low energy response is satisfactory, as mentioned earlier, algorithms for reconstructing individual hadrons are to be developed.

Also, since the search for Centauro events has to be done among minimum bias events and high multiplicities are encountered in these events, it is necessary to investigate whether individual particles can be resolved and their energies measured. For this purpose, Montecarlo simulation of minimum bias events has been carried out and their features studied.

4 Monte Carlo Simulations

About 200 minimum bias events are generated using the ISAJET package[34]. The events consist only of beam jets and no hard scattering at all. In order to be able to identify the individual particles, the minimum separation between particles in the $\eta - \phi$ space should be larger than the DØ Calorimeter resolution.

The ISAJET package stores the energy, momenta, the angle, θ, with respect to the beam direction, the angle, ϕ, in the plane perpendicular to the beam direction, and the pseudorapidity of each particle. Gamma rays, which are the decay products of π^0 and η mesons are also stored.

The quantity $\delta R = \sqrt{(\delta\eta)^2 + (\delta\phi)^2}$ is calculated for each pair of particles in each event. The distribution of the minimum value of δR for the pairs gamma - gamma, gamma - hadron and hadron - hadron are shown in Figs. 3, 4 and 5 respectively. It is seen that mean values are about 0.6 and most of the events have $\delta R > 0.2$. Since the DØ Calorimeter has a modularity of 0.1×0.1 in $\eta - \phi$ space, it is possible to individually identify a majority of individual particles in minimum bias events.

Fig. 6 shows the scatter plot of the total energy in gamma rays, which are essentially due to decay of π^0 and η mesons, *versus* the total energy in hadrons. There are no events in the bottom right corner of the plot, where Centauro events are expected to populate. Processing these events with the DØGEANT package to generate hits and energy deposits in various elements of the DØ Detector, and reconstruction of the events is in progress.

5 Conclusions

Montecarlo simulations show that it is possible to identify individual particles in the DO Detector. Algorithms for reconstructing individual particles have to be developed.

6 Acknowledgments

We express our gratitude to the technical staff at Fermilab for their excellent support. Financial support has been provided by the U.S. Department of Energy, the State Committee for Atomic Energy in Russia, the Commissariat à L'Energie Atomique in France, the U.S. National Science Foundation, the Department of Atomic Energy in India, CNPq in Brazil, the CONACy in Mexico, and Colciencias in Colombia.

7 References

1. C.M.G. Lattes et al. (Brasil-Japan emulsion chamber collaboration), in proc. 13 th Intl. Cosmic Ray Conference, Denver, 4 (1973) 2671.

2. C.M.G. Lattes, Y. Fujimoto and S. Hasegawa, Phys. Reports, 65 (1980) 151.

3. Pamir collaboration and Chacaltaya collaboration, in proc. 20 th Intl. Cosmic Ray Conference, Moscow, 5 (1987) 334.

4. M. Amenomori et al. (Mt. Fuji collaboration), in proc. 20 th Intl. Cosmic Ray Conference, Moscow, 5 (1987) 379.

5. J.R. Ren et al. (China-Japan emulsion chamber collaboration), in proc. 20 th Intl. Cosmic Ray Conference, 5 (1987) 274.

6. K. Alpgard et al.(UA5 Collaboration), Phys. Lett., 115B (1982) 71.

7. G. Arnison et al.(UA1 collaboration), Phys. Lett., 122B (1983) 189.

8. G.J. Alner et al. (UA5 Collaboration), preprint, CERN-EP/86-127.

9. David G. Sutherland, Cosmic rays and particle physics (Edt. by T.K. Gaisser, AIP conference proceedings) 49 (1978) 503.

10. J.D. Bjoken and L.D. McLerran, Phys. Rev., D20 (1979) 2353.

11. S.A. Chin and A.K. Kerman, Phys. Rev. Lett., 43 (1979)1292.

12. J.Dias de Deus and W.A.Rodrigues Jr., Nuovo Cimento, 55A (1980)34.

13. A.K. Mann and H. Primakoff, Phys. Rev. D22 (1980) 1115.

14. R. Anishetty et al., Phys. Rev., D22 (1980) 2793.

15. R. Kinnunen and C. Rubbia, in proc. 17 th Intl. Cosmic Ray Conference, Paris, 11 (1981), 112.

16. I.V. Andreev, J.E.T.P. Lett., 33 (1981) 367

17. G.N. Fowler, E.M. Friedlander and R.M. Weiner, Phys. Lett., 116B (1982) 203.

18. F. Halzen and J.C. Liu, Phys. Rev. Lett., 48 (1982) 771.

19.Demos Kazanas, V.K. Balasubrahmanyan and R.E. Streitmatter, Phys. Lett., 142B (1984) 23.

20. B.S. Acharya et al., proc. 16 th Intl. Conference on Cosmic Rays, Kyoto, 6 (1979) 289.

21. A.M. Dunaevskii et al., proc. 16 th Intl. Conference on Cosmic Rays, Kyoto, 7 (1979) 154.

22. M. Shibata, proc. 16 th Intl. Conference on Cosmic Rays, Kyoto, 7 (1979) 176.

23. T.G. Levina et al., proc. 16 th Intl. Conference on Cosmic Rays, Kyoto, 7 (1979) 148.

24. B.S. Acharya et al., Il. Nuovo Cimento Lett., 31 (1981) 149.

25. R.W. Ellsworth et al., Phys. Rev., D23 (1981) 771.

26. R.A. Mukhamedshin, proc. 17 th Intl. Conference on Cosmic Rays, Paris, 5 (1981) 343.

27. B.S. Acharya and M.V.S. Rao, J. Phys. G: Nucl. Part. Phys., 17 1991) 759.

28. S. Abachi et al., Nucl. Instr. and Meth. A 338 (1993) 185 and references therein.

29. R. Hirosky, DØ Note 1499, Fermilab, March 29, 1993, unpublished.

30. J. Guida, Proceedings of the Third International Conference on Calorimetry in High Energy Physics, Sept. 29 - Oct. 2, 1992 at Corpus Christi, Tx.

31. M. Abolins, D. Edmunds, P. Laurens, J. Linnemann and B. Pi, DØ Note 706, Fermilab, Oct. 25, 1988, unpublished.

32. M. Abolins. D. Edmunds, P laurens and B. Pi, Nucl. Instr. and Meth. in Phys. Research, A289 (1990) 543.

33. J. Mckinley and J. Linnemann, DØ Note 1354, Fermilab, January 20, 1992, unpublished.

34. F.E. Paige and S.D. Protopopescu, BNL Report No. 38304, 1986, unpublished.

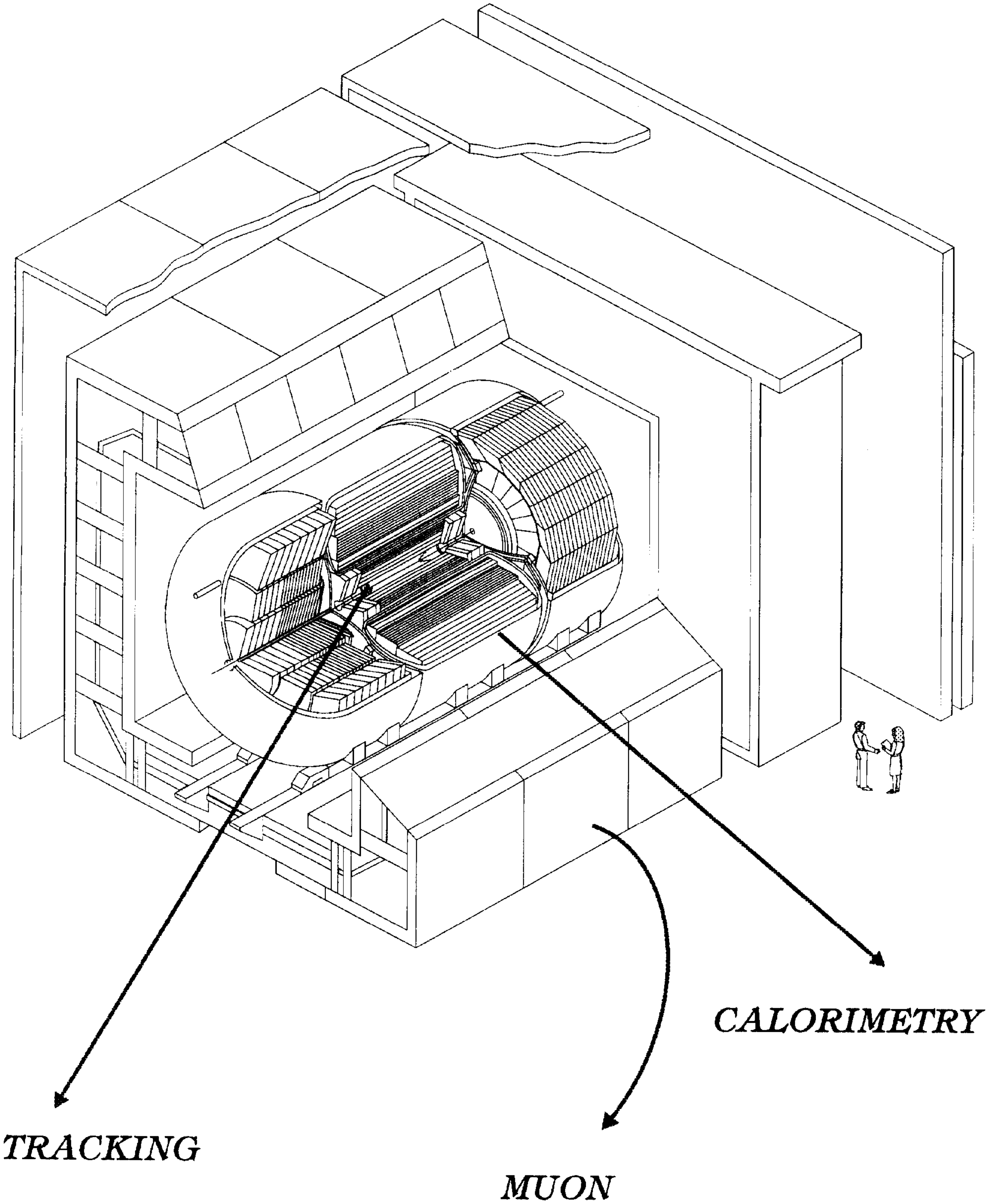

Figure 1: The DO Detector

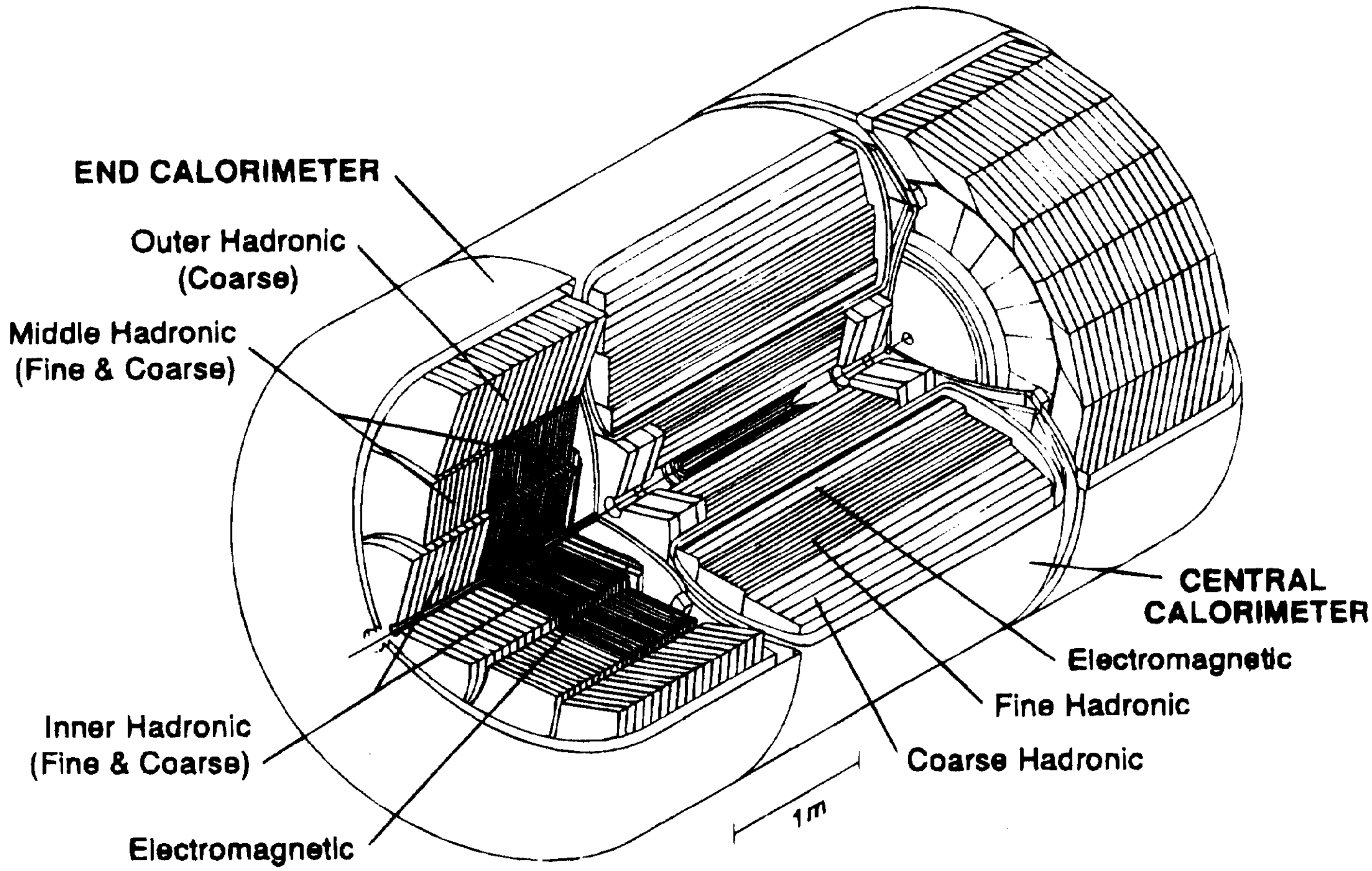

Figure 2: The DØ Liquid Argon Calorimeter

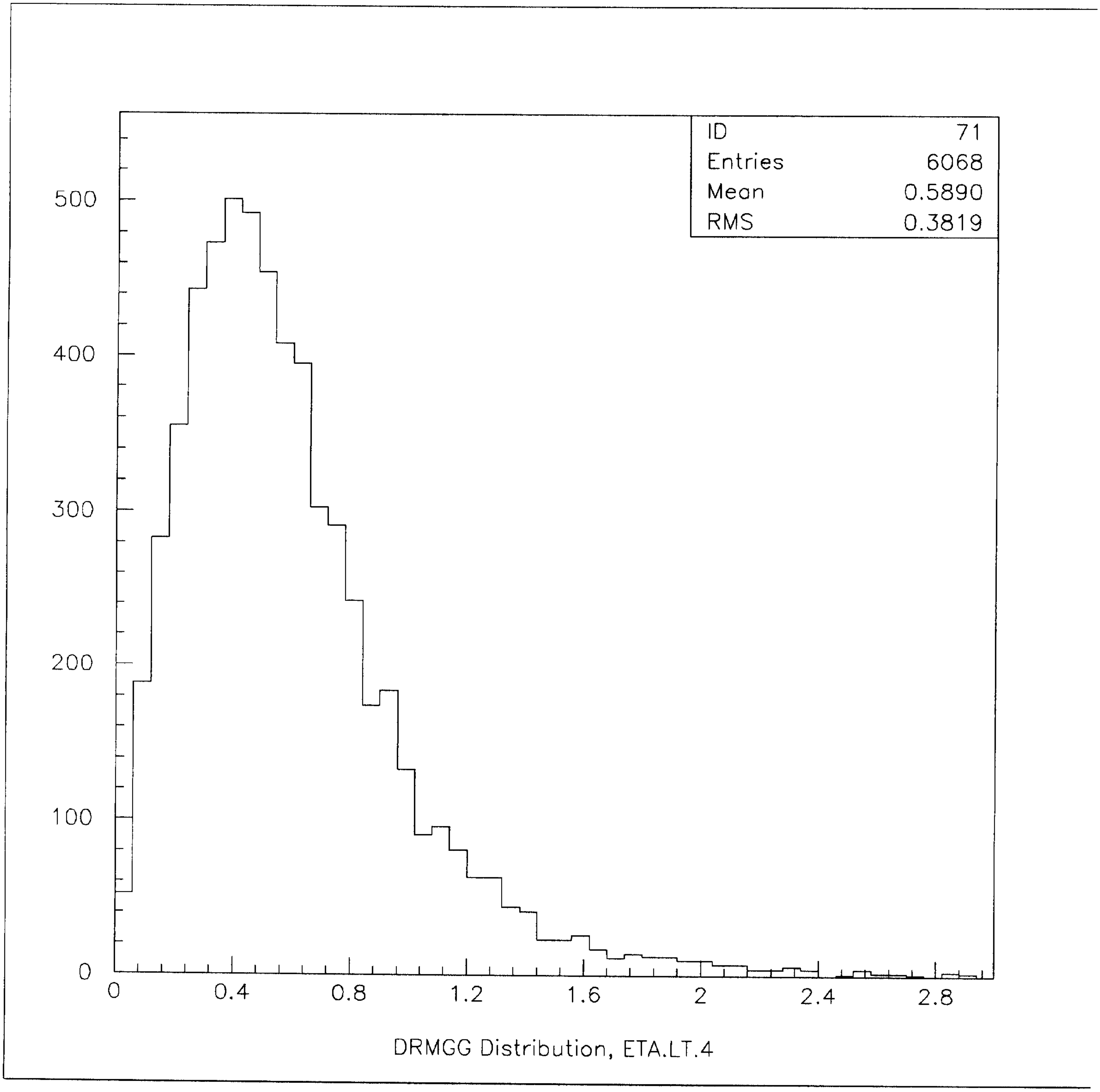

Figure 3: Distribution of δR between γ rays

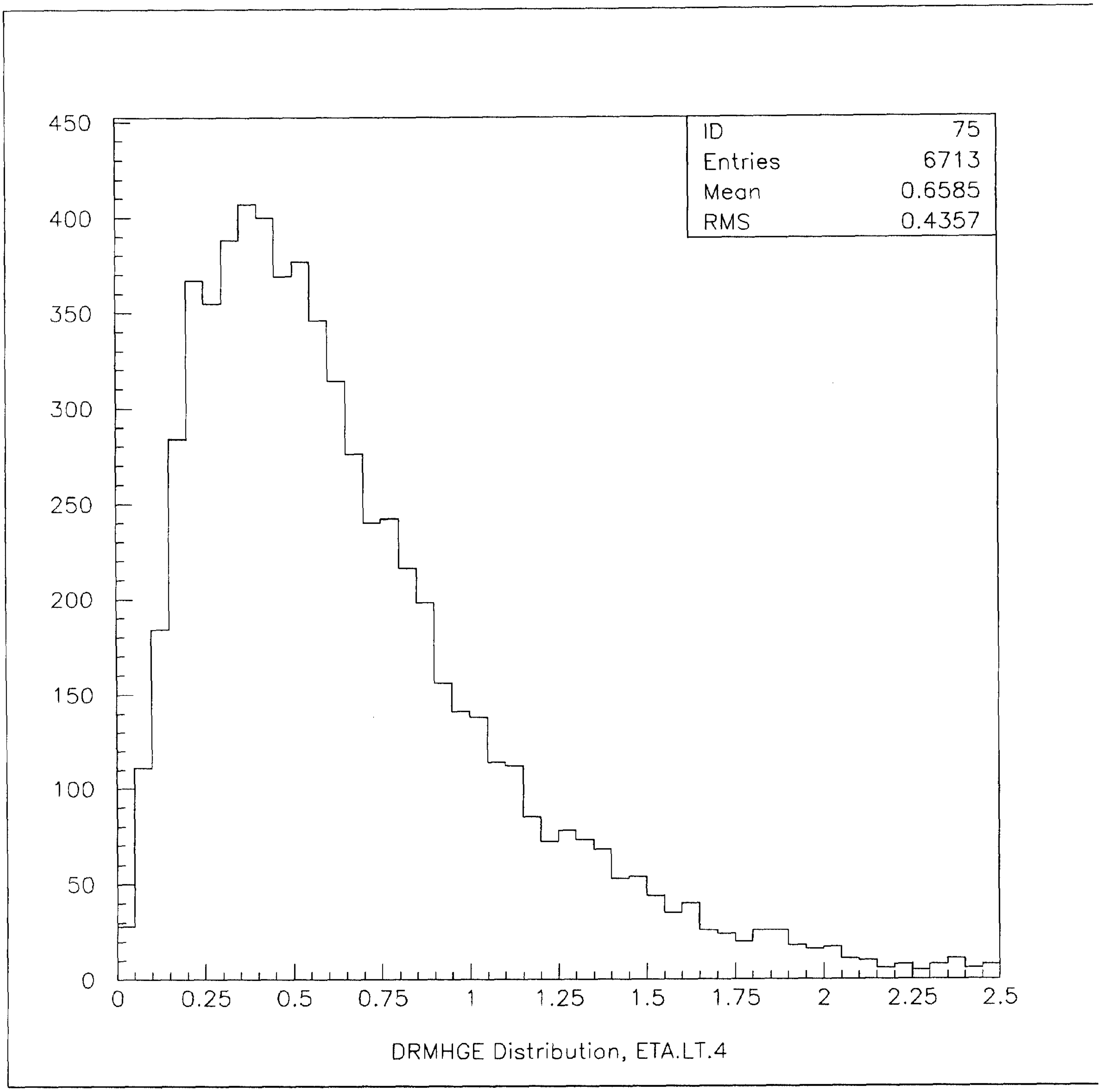

Figure 4: Distribution of δR between γ ray and hadron

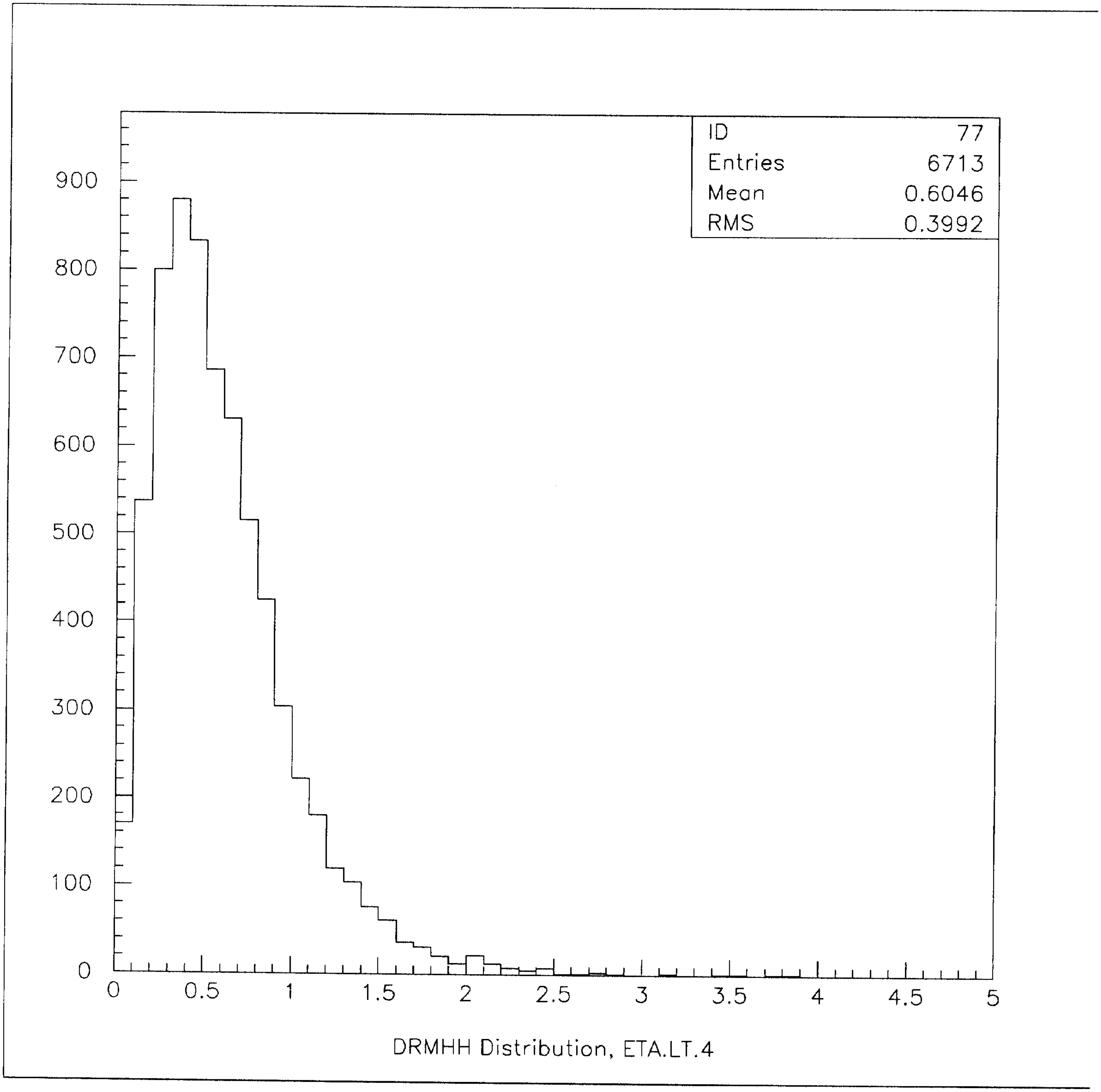

Figure 5: Distribution of δR between hadrons

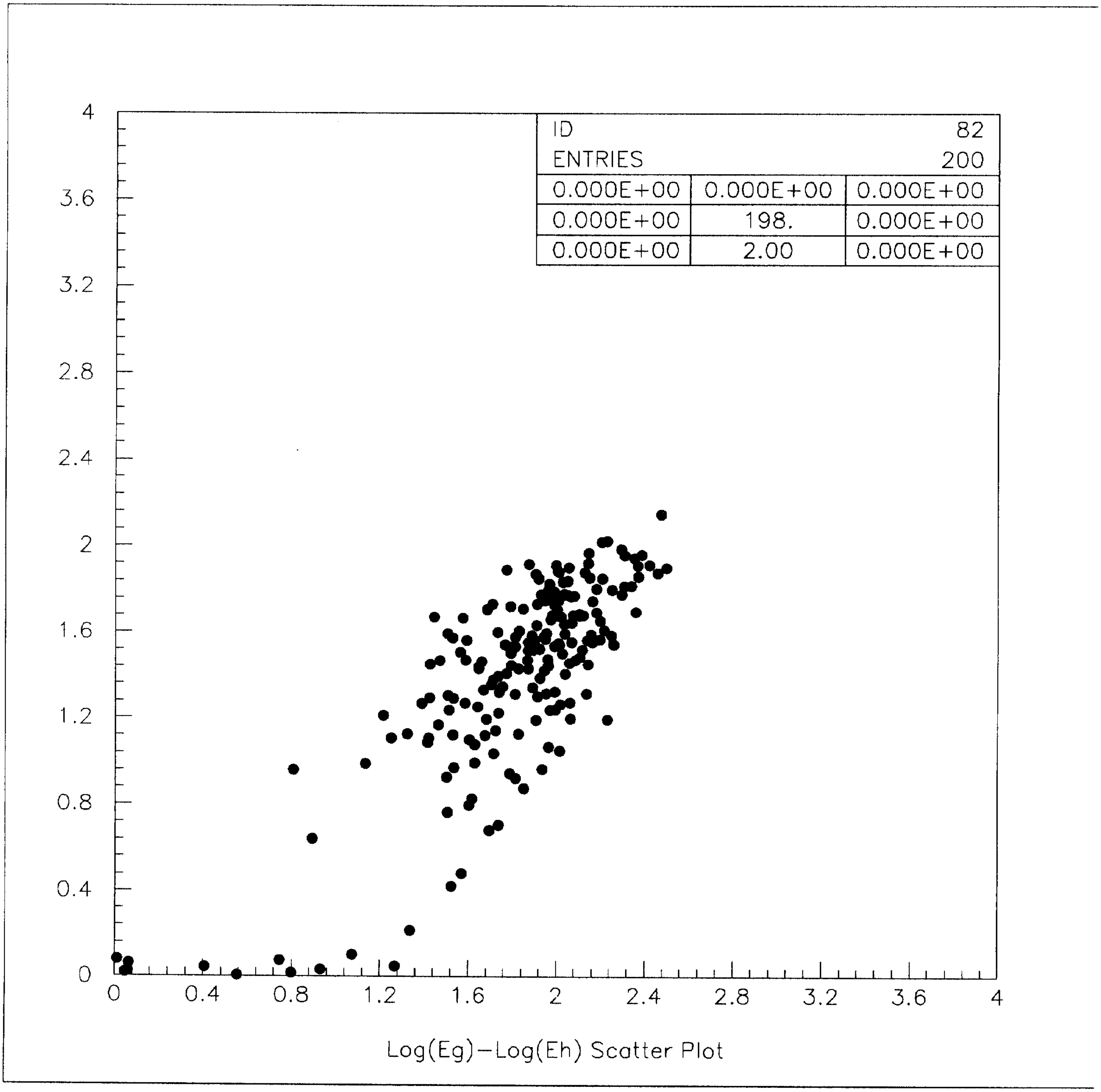

Figure 6: γ ray energy content vs. hadron energy content